MULTIMEDIA UNIVERSITY

STUDENT ID NO

MULTIMEDIA UNIVERSITY

FINAL EXAMINATION

TRIMESTER 1, 2015/2016

ENT3076 – NANOSCIENCE

(NE Students)

17 OCTOBER 2015
2:30 p.m. - 4:30 p.m.
(2 Hours)

INSTRUCTIONS TO STUDENTS

1. This question paper consists of 4 pages including cover page with FOUR questions.

2. Attempt **ALL** questions and the distribution of the marks for each question is given.

3. Please write all your answers in the Answer Booklet provided.

Question 1

A double heterostructure is fabricated by sandwiching an $In_{0.53}Ga_{0.47}As$ layer with two $Al_{0.48}In_{0.52}As$ layers. The thicknesses of $In_{0.53}Ga_{0.47}As$ and $Al_{0.48}In_{0.52}As$ layers are L_{InGaAs} = 1.5 μm and L_{AlInAs} = 1.0 μm and the electron effective masses for $In_{0.53}Ga_{0.47}As$ and $Al_{0.48}In_{0.52}As$ are $m_{InGaAs} = 0.043m_0$ and $m_{AlInAs} = 0.072m_0$, respectively. The conduction band offset of $Al_{0.48}In_{0.52}As$/ $In_{0.53}Ga_{0.47}As$ is 0.51 eV.

(a) Show that the de Broglie wavelength can be written as $\lambda = \frac{h}{\sqrt{2m^* k_B T}}$.

[4 marks]

(b) Calculate the de Broglie wavelengths for electrons in $In_{0.53}Ga_{0.47}As$ and $Al_{0.48}In_{0.52}As$ if the lattice temperature is 10 K.

[4 marks]

(c) If only the thickness of $In_{0.53}Ga_{0.47}As$ layer is decreased to a value smaller than the electron de Broglie wavelength.

(i) Describe the changes in the energy spectra and sketch all the resulted energy spectra.

[3+3=6 marks]

(ii) Describe the changes in the density of states and sketch the resulted density of states.

[3+3=6 marks]

(d) Calculate the first electron energy level if thickness of $In_{0.53}Ga_{0.47}As$ is 10 nm.

[5 marks]

Question 2

(a) $Al_xGa_{1-x}As$ is a ternary III-V compound semiconductor which its material properties could be modified by changing the mole fraction of aluminium (Al).

(i) Discuss the changes on the energy band structure if the mole fraction of aluminium is changing from $x = 0.26$ to $x = 0.75$.

[2 marks]

(ii) Sketch the energy band structures of $Al_xGa_{1-x}As$ for the case of Al mole fraction of $x = 0.26$ and $x = 0.75$. The diagrams must include the **three** conduction band valleys (Γ, L and X valleys) and **three** valence bands (light hole, heavy hole and split-off band) with correct labels.

[4×2=8 marks]

Continued.....

(b) Table Q2(b) shows the material parameters of aluminium nitride (AlN), indium nitride (InN) and gallium nitride (GaN).

Table Q2(b)

Parameter	Nitride Material		
	AlN	**GaN**	**InN**
Energy bandgap E_g [eV]	6.2	3.4	0.7
Electron affinity χ [eV]	0.6	4.1	5.8
Electron effective mass, m^* [m_0]	0.4	0.2	0.1
Parameter	**Heterostructure**		
	AlN/GaN		**InN/GaN**
Conduction band discontinuity ΔE_c [eV]	C1		C2
Valence band discontinuity ΔE_v [eV]	V1		V2

(i) Determine the values of the conduction band and valence band discontinuities for AlN/GaN (C1 and V1) and InN/GaN heterostructures (C2 and V2).

[4 marks]

(ii) Based on the results obtained in part (b)(i), construct the double heterostructure of AlN/GaN/AlN and InN/GaN/InN. Label the value for E_g, χ, ΔE_c and ΔE_v clearly on the diagrams.

[4×2=8 marks]

(iii) If the thickness of the GaN layer is L = 10 nm for the double heterostructure AlN/GaN/AlN, determine the total number of confined energy states in the conduction band of the quantum well.

[3 marks]

Question 3

(a) Describe how (i) **real-space transfer of charge carrier** and (ii) **negative differential resistance effect** could happen in a single quantum well structure.

[5+3=8 marks]

(b) Given that a quantum well mobility μ_W is ten times higher than the barrier mobility μ_B = 800 $cm^2V^{-1}s^{-1}$, the single barrier thickness d_B is five times larger than the well thickness d_W = 10 nm, and the concentrations in barrier and well are $n_B = n_W = 2 \times 10^{14}$ cm^{-3}. If a parallel electric field is established in the double heterostructure quantum well, calculate the current density at 10 V.

[7 marks]

(c) Device engineer has employed the concept of the ballistic electron transport in designing ultra-high speed ballistic-injection device which could operate at cut-off frequency of 20 GHz.

(i) Discuss what is ballistic electron transport phenomenon.

[3 marks]

(ii) Discuss how could the ballistic electron transport be destroyed.

[4 marks]

Continued.....

(iii) Determine the electron velocity in the active region of the device if the barrier potential V_b is 0.5 eV and the effective mass of the material is $m^* = 0.25\ m_0$.

[3 marks]

Question 4

(a) Discuss how the intrasubband phototransition phenomena occur in quantum structures without the involvement of phonons, impurities or other crystal imperfection.

[8 marks]

(b) Compare the differences between the absorption coefficient of a quantum well and the absorption coefficient of bulk material.

[4 marks]

(c) Design a green colour single GaN/InGaN/GaN quantum well laser diode with emission wavelength of 530 nm if the well material has bandgap energy of 2.10 eV, electron effective mass of $m^*_e = 0.12m_0$ and hole effective mass of $m^*_h = 0.60m_0$.

[10 marks]

(d) After a long operation time, the quantum well laser diode will be heated up if the temperature control module of the laser diode is not working. Predict how the increase of temperature in the laser diode will affect its emission wavelength.

[3 marks]

List of constants

Electron mass in free space, $m_0 = 9.11 \times 10^{-31}$ kg
One electron volt, (1 eV) = 1.60×10^{-19} J
Electronic charge, $e = 1.60 \times 10^{-19}$ C
Planck's constant, $h = 6.63 \times 10^{-34}$ Js
Reduced Planck's constant, $\hbar = 1.06 \times 10^{-34}$ Js
Boltzmann constant, $k_B = 1.38 \times 10^{-23}$ JK^{-1}
Temperature in Kelvin, T(K) = T(°C) + 273 K
Permittivity of free space, $\varepsilon_0 = 8.85 \times 10^{-14}$ Fcm^{-1}

End of Paper